

SECONDARY ION MASS SPECTROMETRY (SIMS)

Background

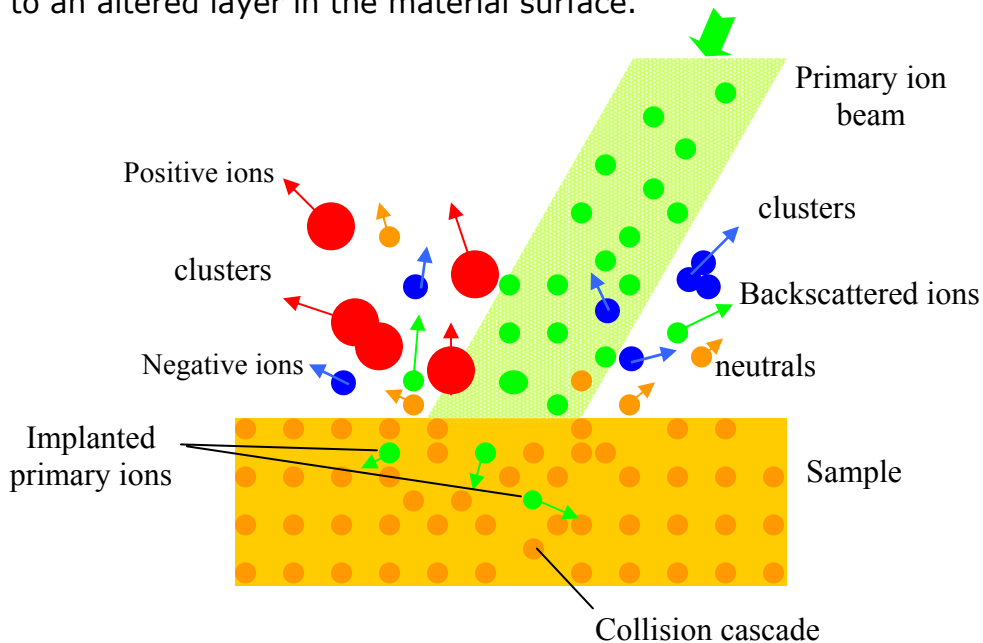
The origins of SIMS may be traced all the way back to the discovery of secondary particle emission by J.J. Thomson in 1910. Subsequently, Arnot and Milligan studied secondary ion emission under positive ion bombardment and Woodcork observed the first known negative ion spectrum from NaF and CaF₂ in 1931. However, the development of modern SIMS instrumentation suitable for analysis purposes was largely through the efforts of Herzog and Viehböck from 1949. In fact, Herzog and his co-workers built the first commercial SIMS instrument under a NASA contract to study the extraterrestrial material brought back to earth from early space exploration. Since then, SIMS has played an important role in the characterization and analysis of semiconductor materials.

Principle of the Technique

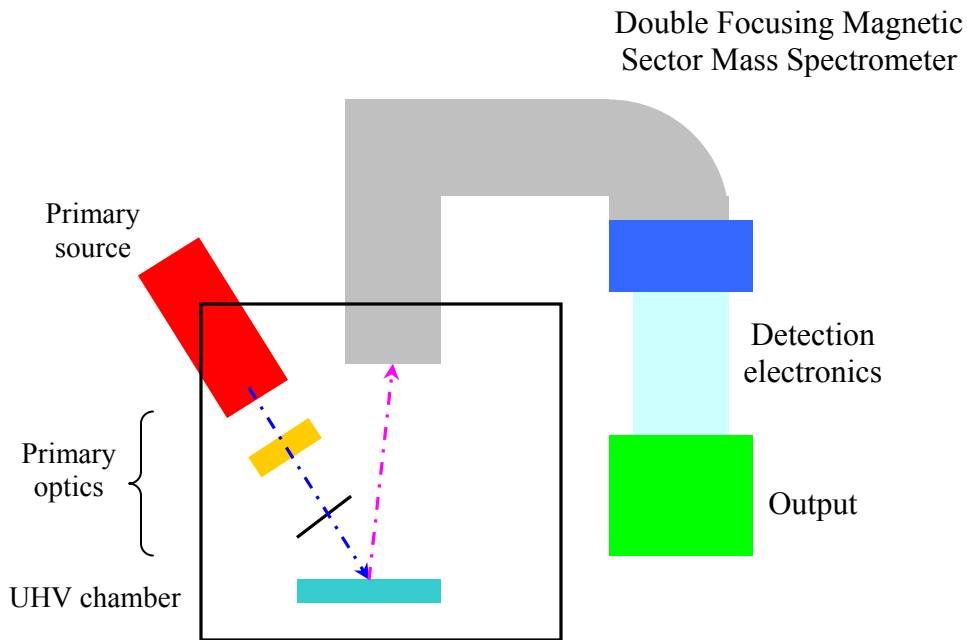
Secondary ion mass spectrometry (SIMS) is a surface analysis technique which basically involves the mass spectrometry of secondary ions. Bombardment of a sample surface by an energetic primary ion beam (~1 – 20 keV) leads to the emission of both neutral and charged particles. The emitted secondary ions are extracted via an electrical potential and analyzed using a mass spectrometer.

Ion Beam Sputtering

Interaction of the primary beam with the sample results in the ejection of secondary ions and neutrals, including molecular fragments and clusters. Ion beam induced atomic mixing as well as implantation of the primary ions give rise to an altered layer in the material surface.



Instrumentation



Schematic of a Double Focusing Magnetic Sector SIMS Instrument

Primary Sources

Primary sources can be reactive or inert. Reactive sources like oxygen and caesium are used to enhance positive and negative secondary ion yields respectively, while inert sources like argon are produced with electron impact sources. Liquid metal ion guns like gallium produce the smallest primary beam spot size and the best lateral imaging resolution.

Mass Analyzers

The three main types of mass analyzers are quadrupole, double focusing magnetic sector and time-of-flight. Each has its own advantages and disadvantages in terms of cost, switching speed, mass resolution, transmission efficiency and mass range detectable.

Detectors

Electron multipliers or Faraday cup detectors are commonly used. Dual-channel plates or resistive anodes are used for image detection.

Specifications

SIMS can detect all elements from H through U with a detection sensitivity of ppm (parts per million) or even ppb (parts per billion) level. It can also distinguish between isotopes of the same element. Detection limits vary with both element and instrumental parameters and can range from 10^{13} at/cm³

to 10^{17} at/cm³ for common impurities in semiconductors. A typical depth resolution of ~ 10 nm is achievable for routine samples. Some insulators may be analyzed with the use of electron charge compensation. An approximate quantification of the elemental composition can be achieved using standard reference materials and relative sensitivity factors (RSFs).

Disadvantages

- Mass interferences are often present
- Secondary ion yields are often highly dependent on the matrix
- Secondary ion yields vary by more than six orders of magnitude across the elements
- Destructive
- Well-characterized reference standards that are as close as possible to the matrix of the samples of interest are needed for quantification
- Element of interest should be in the dilute concentration regime (<1%) to exclude matrix effects

Points to Note

- Sample must be compatible with ultra-high vacuum
- Samples must generally be flat for magnetic sector instruments
- Presence of surface transients requires caution when quantifying top ~ 50 nm of surface
- Surface roughness effects
- Sputter-induced atomic mixing and topography can degrade depth resolution
- Quantification from multilayer structures is complex, as ion yields vary from matrix to matrix and also at the interface between layers

Operation Modes

Although mass spectra and ion images are achievable, depth profiles are by far the most common application of dynamic SIMS.

Applications

SIMS is widely used for ion implant characterization, thin film analysis and trace contamination analysis in microelectronics industries. It is a major analytical tool in the areas of quality control, failure analysis and process development. The instrument at IME, the CAMECA IMS 6f, is a magnetic sector SIMS with high mass resolution and is optimized for obtaining dopant depth profiles in semiconductors with excellent dynamic range.

Examples

Figure 1: B-implanted wafer

Figure 2: Trace metal contamination in SiO₂

Figure 3: Depth profile of multilayer SiGe/SiC sample

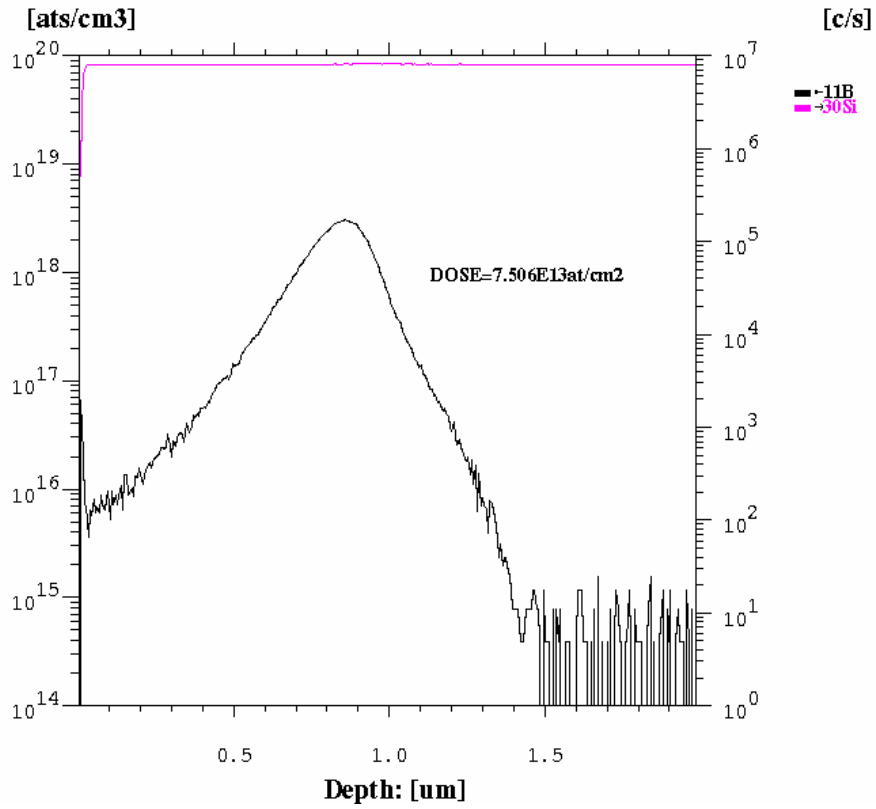


Figure 1: Depth profile of a boron implant

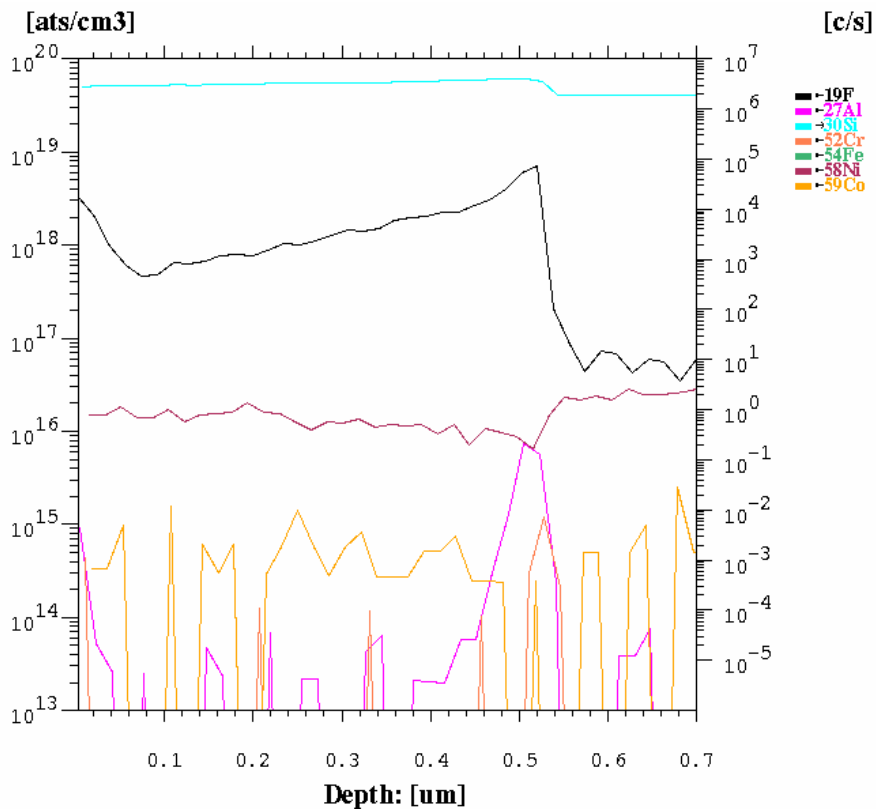


Figure 2: Trace metal contamination in SiO_2

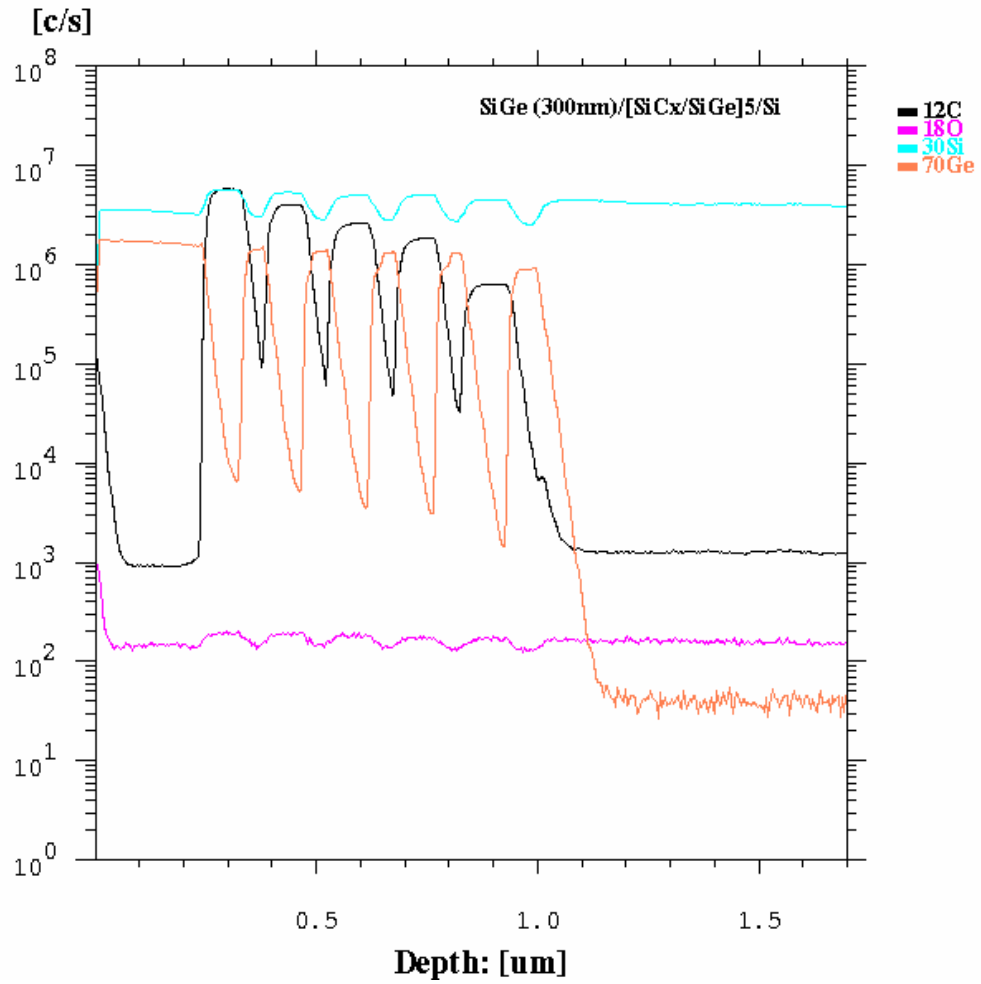


Figure 3: Depth profile of a SiGe/Si_{1-x}C_x multilayer film stack